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# An intermediate image β-spectrometer of high transmission

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With 14 figures in the text

## 1. Introduction

In order to achieve space focusing of electrons, long and short magnetic lenses have been used for some time in β-ray spectroscopy. As is well known the main advantage of these instruments is the high transmission power that can be obtained. The resolving power is determined by a number of factors and particularly the spherical aberration of the lens is the important factor, which ultimately puts an upper limit for the maximum solid angle, which can be used. This error is worse for short lenses than for long lenses. By varying the field form along the axis the aberration can be changed within certain limits. Thus, simple considerations show[1] that a field with a negative value of $\frac{\partial H_z}{\partial r}$ ($H_z =$ the field along the axis of the lens) inside the focusing region is desirable. This condition also implies that the field along the axis has to have a minimum between the sample and detector. The short lens does not satisfy this condition, since the field distribution in that case can be described by a bell shaped function, with a maximum in the center of the lens.

Naturally all focusing systems will have some sort of spherical aberration. This aberration increases when electron paths are used, which are relatively far away from the optical axis of the system. If the outer part of the electron beam is screened off by means of a shutter system so that only the central or paraxial rays are used for focusing the spherical aberration will be less pronounced. This can be done with the semicircular method, which on the other hand does not afford space focusing. The double focusing method[2] with a shaped field varying as $\frac{1}{\sqrt{\varrho}}$ ($\varrho =$ distance from the center of the magnet), can, however, use central rays and simultaneously achieve space focusing.

In the case of a lens one cannot use central rays, which on the contrary have to be screened off by a central shutter. The resolving power, defined as $\frac{\Delta H\varrho}{H\varrho}$, for a short lens is then approximately given by

$$\frac{\Delta H\varrho}{H\varrho} = \frac{s + w}{4D}$$

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[1] K. Siegbahn, Phil. Mag. XXXVII, 162, 1946.

[2] N. Svartholm, K. Siegbahn, Ark. f. Mat., Astr. o. Fysik *33* A, N:o 21, 1946; K. Siegbahn, N. Svartholm, Nature *157*, 872, 1946.

where $s$ and $w$ are the diameters of the sample and the detector slit and $D$ the diameter of the central shutter. If the spherical aberration is not taken into consideration the resolving power thus increases inversely proportional to the central shutter. In practice this is soon counter balanced by the increasing spherical aberration for electrons making larger angles with the optical axis. In spite of this circumstance the lens method is capable of giving higher transmission factors than most other methods at least when comparisons are made at moderate resolving powers, *e. g.* when the advantages of the central rays are less pronounced. One of the reasons for this is that the actual loss of intensity by cutting off the central parts of a wide conical beam is not too great since the transmitted radiation increaes as the square of the radius of the central shutter.

To sum up, the limitations of the ordinary lens method is primarily caused by the spherical aberration, which is accentuated (especially when good resolving powers are desired) by the fact that no central rays can be used.

It was mentioned before that the spherical aberration is decreased if the field along the axis is shaped in such a way that a minimum instead of a maximum (as for the ordinary short lens) is obtained between sample and detector. A focusing device of this type has earlier been investigated in our laboratory.[1] It was found that the aberration actually decreased and it was thought possible to get along further on these lines. A new spectrometer was designed, in many respects similar to the older, except for some constructional details. Furthermore, the coil system was designed with the special purpose of making it possible to change the field gradient in the lens by varying the ratio of the currents through the different coils. In this way it was possible to achieve even quite strong gradients and to investigate the focusing behaviour of the spectrometer as a function of these gradients. At the same time a number of other parameters could be varied, such as shutters, position and size of sample etc. The technique used at these focusing experiments was based on either the investigation of $\beta$-line profiles registered with ordinary G. M. technique or photographic tracing of the electrons along their paths in the spectrometer. Especially the last method, which earlier[2] has been used here to investigate similar questions, was found to be useful.

The results of these investigations, which will be presented in this paper, have revealed a new and very powerful type of focusing, which can be obtained if the field gradient and some other parameters are properly adjusted. Thus, it will be shown that a certain gradient can form a ring formed, intermediate image midway in the spectrometer, whereafter a second point image is obtained at the slit of the G. M. detector. This "intermediate image" or "twofold" focusing device has many interesting properties, such as exceptionally high transmission power etc. and these will be discussed in more detail in the following.

## 2. The new $\beta$-spectrometer

Our intention was to build a lens spectrometer, in which the magnetic field form and other experimental conditions could be changed easily. The diameter of the vacuum chamber should be sufficiently large to permit the focusing of even such $\beta$-rays, which are emitted from the sample with a large angle relative to the lens

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[1] K. SIEGBAHN, Phil. Mag., loc. cit.

[2] H. SLÄTIS, Ark. f. Mat., Astr. o. Fysik, 32 A, N:o 20, 1945.

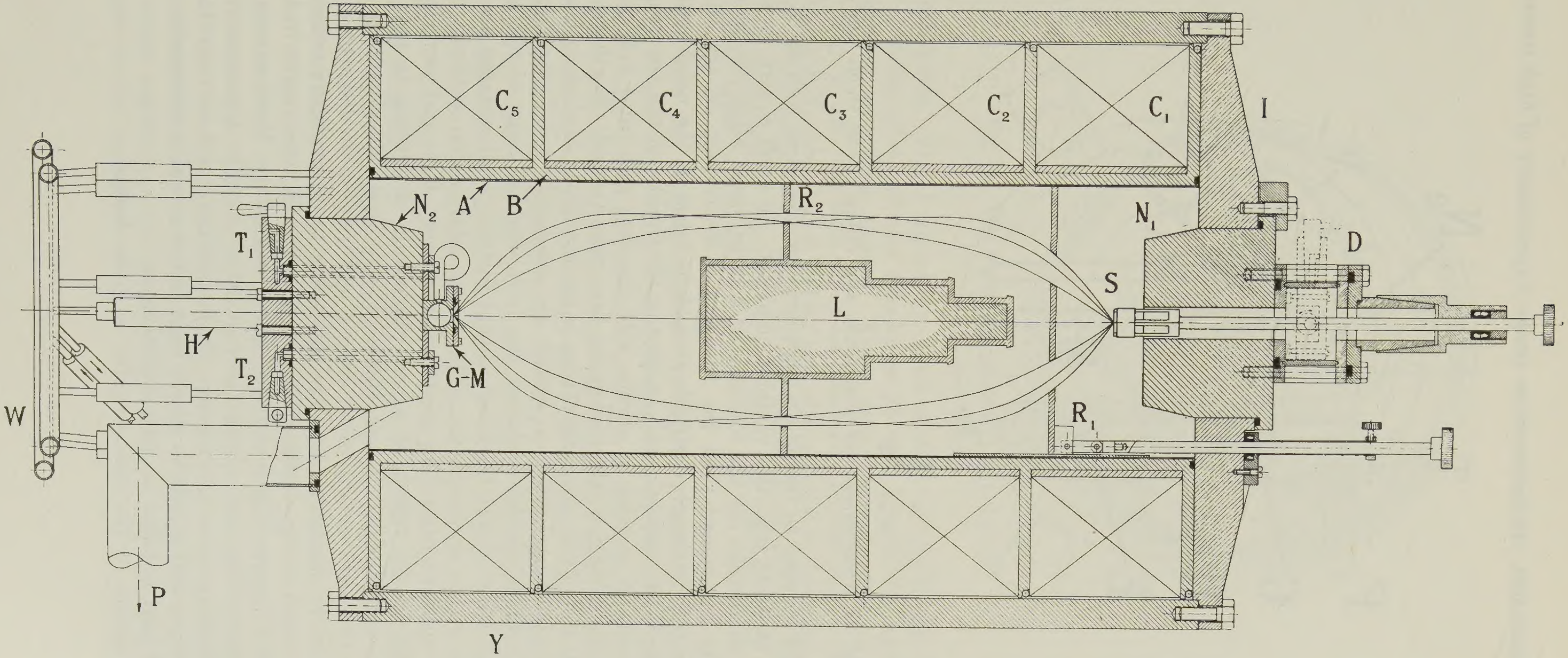

Fig. 1. Axial section of the spectrometer.

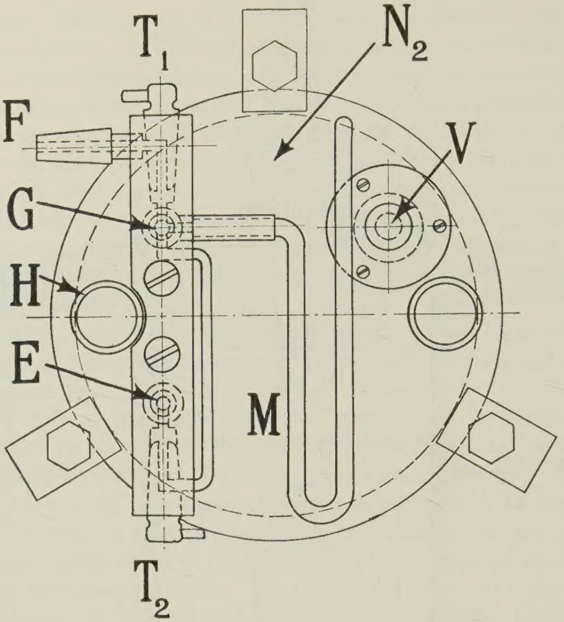

Fig. 2. Arrangement for evacuating and filling of the G. M. tube.

axis. It should be easy to introduce photographic plates as well as G. M.-counters and different shutters into the vacuum chamber. In such a way it was hoped to find the best conditions for the focusing of a large space angle electron beam.

It is already mentioned that the focusing is dependent on the magnetic field gradient. The field strength desirable should be large in the neighbourhood of the sample and the G. M.-counter, and smaller in the middle of the spectrograph. Such a magnetic gradient is easy to obtain with an iron yoke and pole pieces. There will also be some saving of effect when an iron yoke is used. Furthermore, a closed yoke is a good shield for outer disturbing magnetic fields (including the earth field) and provides good possibilities to obtain an accurately axial symmetric field distribution. Therefore, we have chosen the iron shielded form of the spectrometer.

On the other hand it may be objected that certain disadvantages are encountered by using iron in the spectrometer. The linear relationship between the magnetic field and the current cannot be relied upon at very high and very low fields (for instance in the energy region of Auger electrons). According to our previous experience with iron shielded lenses, this is a very small disadvantage. In the low energy region there are usually other effects, which are more disturbing than a slight departure from the linearity, *e. g.* line shifts due to absorption in the sample itself etc. In these cases energy determinations of unknown lines ought to be performed relative to other known β-lines under identical conditions. Furthermore, the relation between magnetic field and current in regions of possible departure from linearity is easy to determine once and for all. These questions will be more fully discussed later in this paper and it will be shown that in the actual spectrometer the linearity between field and current is quite satisfactory.

The construction of the spectrometer is given below.

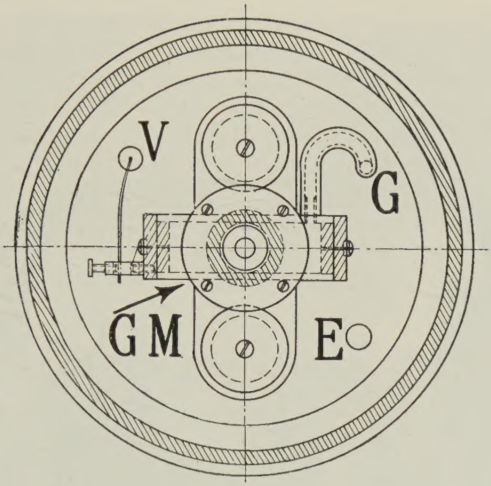

Fig. 3. The mounting of the G. M. counter.

**a. The iron yoke.** Fig. 1 shows an axial section of the β-spectrometer. The iron yoke $Y$ consists of a cylinder (thickness 25 mm, length 700 mm), the ends of which are covered with iron disks $I$. These disks are mounted on small railway waggons (see Fig. 4) and can thus easily be removed. In the centers of the disks the pole shoes $N_1$ and $N_2$ are placed. They can also simply be inserted or taken out. The diameter of the disks is 520 mm, the thickness 25 mm on the perifery, and 50 mm in the neighbourhood of the pole shoes, which are 110 mm thick. The distance between the pole faces is 610 mm.

**b. The coils and the cooling system.** In order to make it possible to change the magnetic gradient, the coil is separated into five different parts $C_1, C_2, \ldots C_5$. This arrangement also facilitates the cooling of the coils, since the copper disks are separately cooled and therefore effectively can transport heat from the coils. The coils consist of 2.3-mm diameter cotton covered copper wire, wounded between the six copper disks on a brass cylinder $B$. The cylinder and the disks (thickness 1 cm) are cooled by water, circulating in copper tubes of 6.35-mm outside diameter. Six ducts are connected in parallel with the two ring shaped water tubes $W$, each duct going lengthways the outside of the cylinder and lengthways the perifery of one of the disks. Copper sheets of 6.35-mm thickness are placed between the different cooling tubes on the cylinder. Thus, an even surface on the cylinder is obtained.

The total number of turns in the coils is 5 × 1960 and the resistance is 45.5 ohm.

**c. The current stabilizer.** The current for the coils is delivered by a motorgenerator (440 volt) of a maximum effect of 7.5 kW. The current from the generator is regulated by the magnetic field on the generator and is kept at a constant value ($\pm$ 1‰) by means of a current stabilizer designed for our spectrograph by civ.ing. G. Dahle (ASEA). The potential drop on a resistance in the main circuit is automatically and continuously compared with the standard voltage on a battery, and the difference voltage regulates a direct current amplifier, which supplies the current for the magnet in the generator.

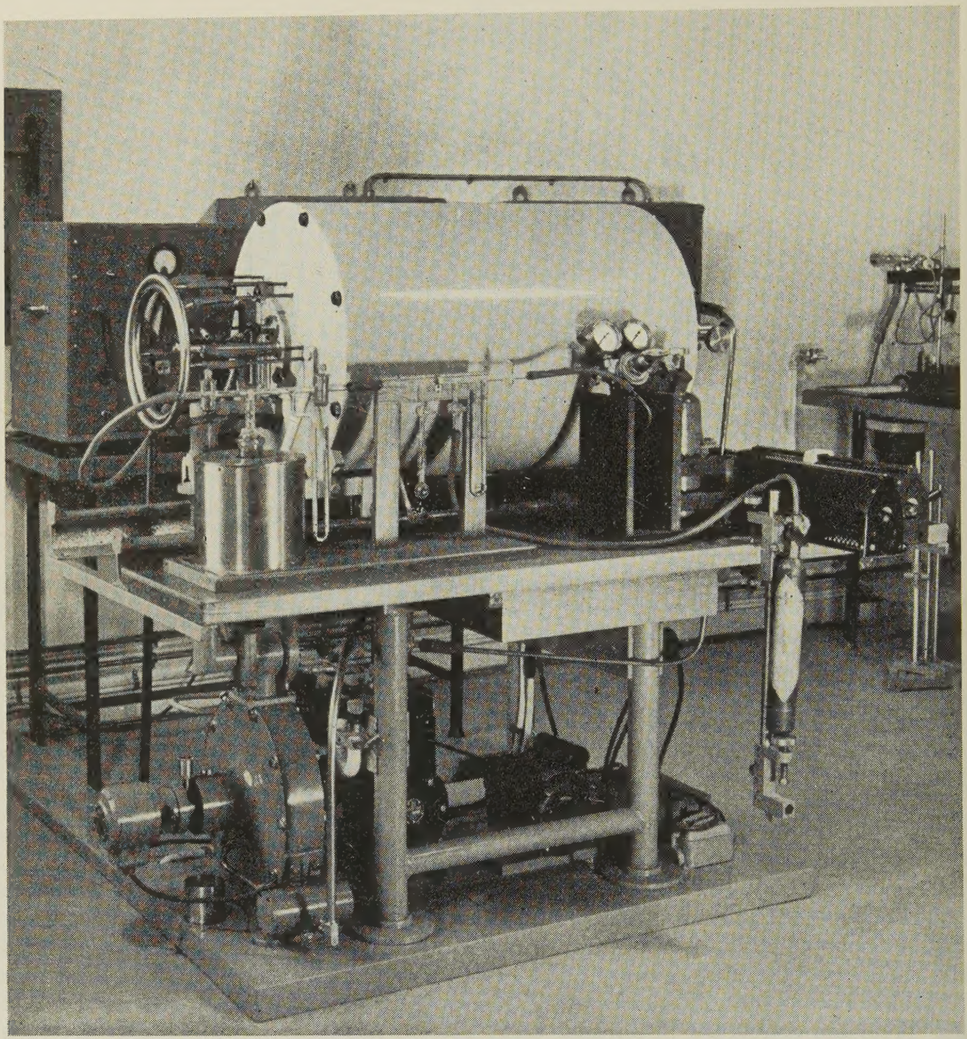

Fig. 4. Total view of the spectrometer. In front of the spectrometer the G. M. counter filling apparatus is situated. To the left of the spectrometer, part of the cooling system can be seen. On the other side the vacuum lock device for the sample is situated (almost masked by the spectrometer). Behind the spectrometer the counting equipment and current regulating and stabilizing arrangements are located.

**d. The vacuum system and the Geiger-Müller counter.** The space between the brass cylinder and the iron disks with the pole pieces is sealed with rubber gaskets and evacuated by a Welch two stage duo-seal vacuum pump as backing pump in connection with a molecular pump.

The Geiger-Müller counter (G.-M. in Figs. 1 and 3) is made of a brass square bolt of 70 mm length and 25 mm side, in which a hole of 70 mm length and 20 mm diameter is drilled. The ends of the tube are closed with ebonite disks, through the centers of which the wolfram anode wire is drawn. In the middle of the tube a nylon window of $\gtrsim 1\ \mu$ thickness and 8 mm diameter is situated. The space of the counter is evacuated by connection with the vacuum system through the tubes $G$, $E$ (Figs. 2 and 3) across the cock $T_2$. The tube is filled with a mixture of 40 mm methan and 60 mm argon across the tubes $F$, $G$ and the cock $T_1$ (Fig. 2). $F$ is connected with a bottle (2500 $\text{cm}^3$), in which the gas components are mixed and kept. The bottle is placed in a cylindrical brass container, which is seen to the left in Fig. 4. The tubes with argon and methan as well as the pressure gauges are also seen in the figure. By means of the cable $V$ in an ebonite cylinder, the anode wire is connected with a recording circuit, which consists of a voltage stabilizer, a preamplifier and a scale of 100.

## 3. Focusing experiments

Two methods of investigating the spherical aberration and other properties of the lens were used. The first of these was to select three electron beams emerging from the sample with different angles relative to the axis by introducing a central shutter with 3 circular apertures of different radius. The source used was ThB, which contains the very useful strong $F$-line ($H\varrho = 1383.8$). If the current through the coils is varied and the intensity at the G.-M. counter is measured, one obtains a line pattern (see Fig. 5) consisting of three lines, because of the spherical aberration. The distances between the lines $\Delta I$ divided by the current $I$ is a relative measure of the aberration. This line pattern was investigated with the magnetic field gradient as a parameter. The field gradient was adjusted simply by changing the ratio of the current through the middle coils $C_2C_3C_4$ to the outer coils $C_1C_5$. $C_2C_3C_4$ and $C_1C_5$ were in parallel.

Since the spherical aberration for a magnetic lens is always positive, that electron beam emerging from the sample with the smallest angle relative to the axis, *i. e.* the one passing the circular aperture with the smallest radius, must correspond to the line, which is focused with the highest current value etc.

When the field gradient was increased, the line pattern was shifted to higher total currents. Simultaneously the intensity of the three lines increased and for smaller gradients in almost the same proportions.

When the gradient became very much stronger a peculiar fenomenon appeared. The line focused at the smallest current (*i. e.* the one corresponding to the outer electron beam) *started to grow up considerably compared to the other two.* When the gradient was made still stronger, this line rather quickly *dropped again* in intensity. Simultaneously the next line started to grow up and became much stronger than the other two, whereafter its intensity dropped. The same happened then to the third line at even higher gradients.

The radii of the three central shutters were 61, 85 and 109 mm (8 mm wide) and the corresponding peak values for the three lines appeared when the current ratio $I_{2,3,4}/I_{1\text{-}5}$ was as low as $-0.05$, 0.07 and 0.12 respectively.

At this stage of the experiments the explanation for the appearance of the high line peaks was not completely understood and the lines were rather broad, especially at the low energy side. The very high counting rate at the top of the lines showed however that if the problem of the line width could be mastered without too much loss of intensity the new device could turn out to be very useful.

Before trying to do that, a second photographic method to investigate the be-

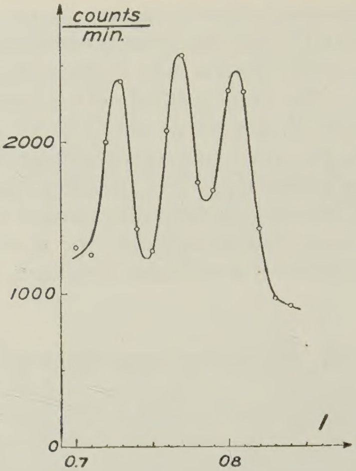

Fig. 5. Line pattern due to spherical aberration. In this case all coils were in series.

haviour of the lens was introduced. If plates were placed with their planes along the lens axis, and if the current was set to focus the strong $F$-line, the electron beam passing the shutter could be considered as monokinetic because of the small intensity of the continuous spectrum in the neighbourhood of the line.

The applicability of the method is well illustrated in Fig. 6. In this case all coils were in series giving a comparatively homogeneous field. A rough field map, giving the directions of the lines of force, is shown above in the Fig. This map was simply obtained by spreading out iron powder uniformly on a large piece of photographic paper, placed in the spectrometer, then turning on the field and exposing it to light. In the lower part of the Fig. 6 the paths of the three different electron beams are shown. The axis of the lens is marked by the continuous spectrum. The positive spherical aberration of the system is very clear according to this picture.

It would be an easy matter to use Fig. 6 to introduce a ring baffle, conveniently situated where for instance two of the rays cross each other. To collect all electrons emerging from such a ring baffle, a very large counter is necessary if high intensity is wanted. This focusing device has first been used successfully by WITCHER.[1]

It was soon found that the lines at the high gradient field could be made appreciably sharper with small loss of peak intensity if a shutter $R_1$ was introduced between the sample and the middle shutter $R_2$. The proper adjustment of this important shutter will be discussed later. In Figure 7 the above photographic method has been applied to the case when the gradient is adjusted for high line peak, corresponding to the radius of the shutter $R_2$ and when the shutter $R_1$ was introduced. The field map for that case is illustrated above in the figure. Fig. 7 is interesting since it immediately shows why this particular field gradient gives such a high peak value. Actually all electrons in the wide angle electron beam is focused to one point on the slit of the small counter instead of spreading out along the axis due to the spherical aberration as in the previous case. Another circumstance, which increases the effect is of course the greater mean angle ($\sim 45°$), which the beam makes relative

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[1] C. WITCHER, Phys. Rev. *60*, 32, 1941.

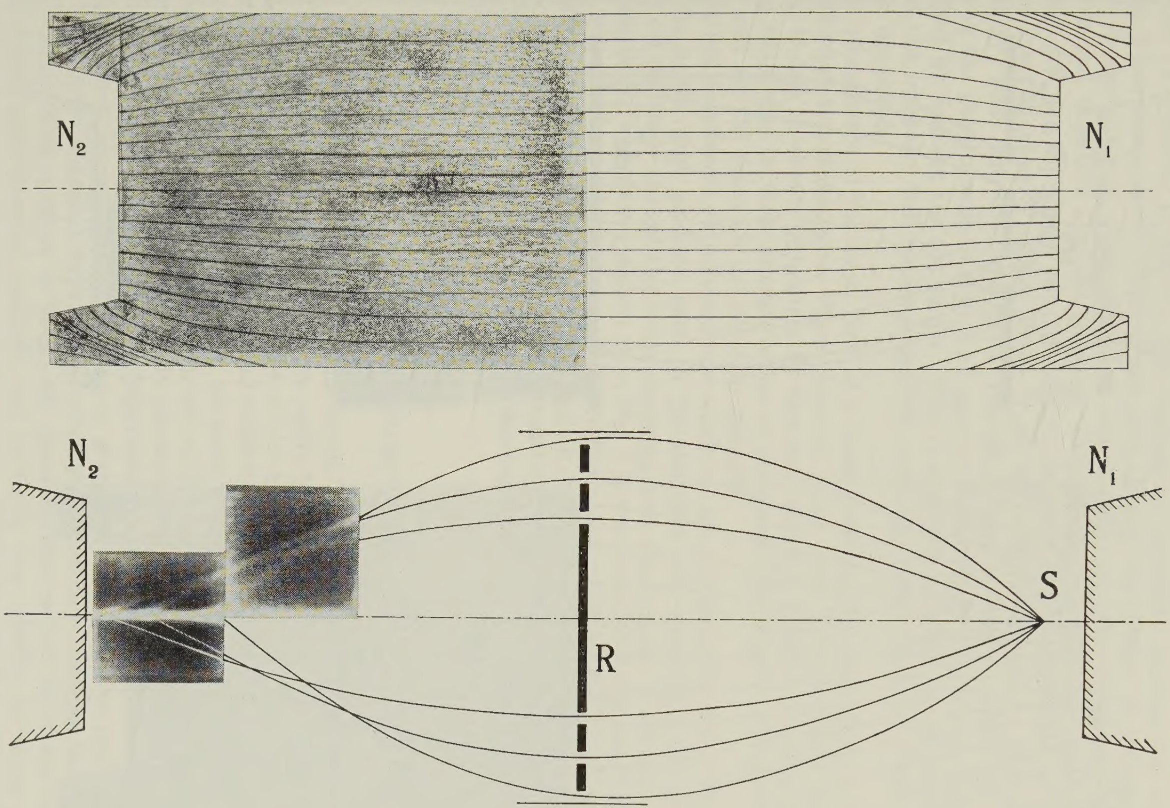

Fig. 6. The spherical aberration of the lens illustrated by the photographic method. All coils were in series and the resulting field is shown above in the figure.

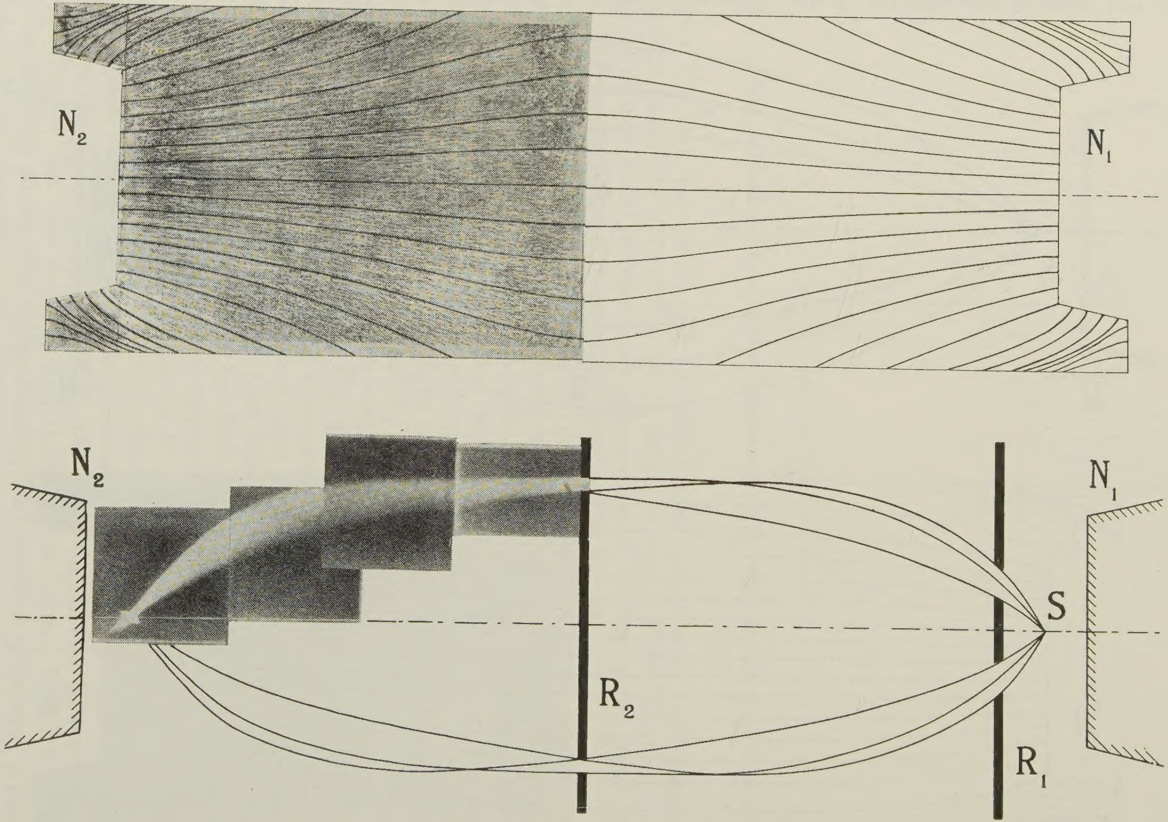

Fig. 7. The new type of focusing investigated by the photographic method. This picture is taken after the shutters $R_1$ and $R_2$, current ratio and sample position has been properly adjusted. Above the corresponding field map.

to the axis. This phenomenon is connected to the fact that the field is particularly strong near the sample and detector.

Another feature of importance for the understanding of the focusing principle, can also be observed in Fig. 7. The continuous spectrum forming the axially line in Fig. 6 has disappeared. This means that already the shutter $R_2$ selects a certain small energy interval of the electrons, which ever can enter the space behind this shutter and therefore also the counter. In one sense we therefore have our G. M. counter defining slit placed not immediately in front of the counter but in the middle of the spectrometer. The size of the G. M. slit is therefore not so critical as for a "straight" lens. Provided the size of the slit is large enough to collect the electrons forming the point image in Fig. 2 no gain in intensity nor any loss in line width is obtained by making the slit larger. This is of course contrary to the straight lens, where the intensity will increase and the resolving power go down when the G. M. slit is increased.

The appearance of the small part of a beam crossing the main beam at the focus is somewhat surprising, since these electrons must come from the other side of the plate. It can be shown geometrically however that it is possible for some electrons in the beam due to their twisted orbits to go around the edge of the photographic plate and hit the plate on the place in question.

A rather conclusive experiment was made to get a first indication of the way of focusing in the high gradient case. A circular desk was inserted at the shutter $R_1$ to cut off the *inner* part of the beam emerging from the sample. If the beam leaving the shutter $R_2$ was photographed as in Fig. 7 it was found that the *outer* part of the beam was missing. This showed that the beam was crossing itself and there were also strong indications that this happened at the shutter $R_2$ itself or very near there. In such a case one would expect a symmetric geometry in the focusing. This was confirmed in detail by the experiments dealing with separate electron paths, which will be described next.

## 4. The β-ray paths

We have shown above that the axial distances of the different parts of the rotational symmetrical electron beam, can easily be recorded by means of photographic plates, placed in planes along the axis of the spectrometer. It may, however, be of interest to know the three dimensional paths of single β-rays. For a closer examination of these paths one can choice between a mathematical-graphical or a pure experimental method. By the mathematical method one has to know the magnetic field in the lens volume, preferably by experimental means. When solving the differential equations for the path of the β-particle from point to point in space one has, for convenience, to use approximations or graphical methods. The paths thus constructed, will be obtained with smaller or greater errors depending on the approximations made. This method is under all circumstances rather laborious compared with a direct, experimental method, and probably less reliable for many cases.

A very convenient, experimental way to do this is to use the above described photographic method. In this case the active deposit was situated on a small sphere (2 mm diam.) so that the sample could be considered as a point source. By means of a small circular hole in a diaphragm a thin electron pencil could be taken out and investigated. A photographic plate perpendicular to the axis of the spectrometer

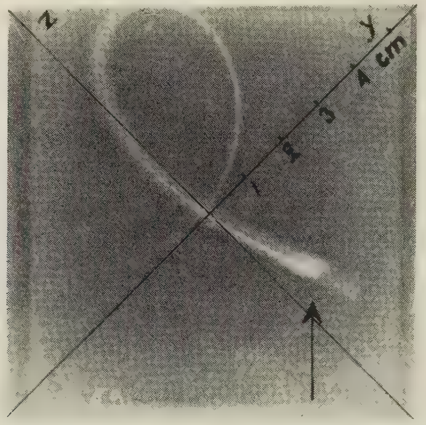

Fig. 8. Photographic picture taken of a single electron pencil falling on a plate perpendicular to the lens axis. This pencil contains the energy spectrum of ThB + daughter products, but the light spot on the curve corresponds to a definite energy, namely the energy of the *F*-line.

was then placed at different positions in the spectrometer. Thus, arbitrarily many points along the electron path could be obtained. As far as we know, this method has not been used before in this connection.

Another way to perform this investigation would be to use an electron gun. In that case some difficulties are encountered when trying to get out electrons of a definite energy in all directions. These difficulties are avoided using the above method, which otherwise also is experimentally much simpler.

By use of the photographic method with electrons from ThB one gets of course besides electrons from the *F*-line the continuous spectra from ThB and its decay products. On a photographic plate perpendicular to the axis a curve is therefore obtained, on which the *F*-line is marked by a dark spot. Fig. 8 shows a positive of such a plate, which was exposed 5.7 cm from the pole surface on the G. M. side of the spectrograph. This photo gives one of the points on the full drawn electron paths in Fig. 9.

Fig. 9 shows five different electron paths, obtained with the above method. The diaphragm hole was 3 mm in diameter and was placed 61 mm from the sample $S$. $\varrho$ is the distance of the β-ray from the axis. $z$ is the vertical projection and $y$ the horizontal projection of the β-ray path. $M$ is the middle of the spectrometer. To the right a vertical projection of the paths in a plane perpendicular to the axis is given. Paths with very different emission angles with the axis were also studied. We see that the three paths passing the holes no. 2, 3, and 4 are very accurately focused in a single point on the axis of the spectrometer. These three paths have the largest $\varrho$-values in the middle of the spectrometer (the $\varrho$-values for the path with the maximum $\varrho$-value are symmetrical regarding to the line $M$) and are rather well focused here. To obtain good resolution the inner and outer paths should be screened off by the sample shutter $R_1$.

It is seen from the projection in the $yz$-plane that the electron paths are twisted, corresponding to a total rotation of image of about 427°.

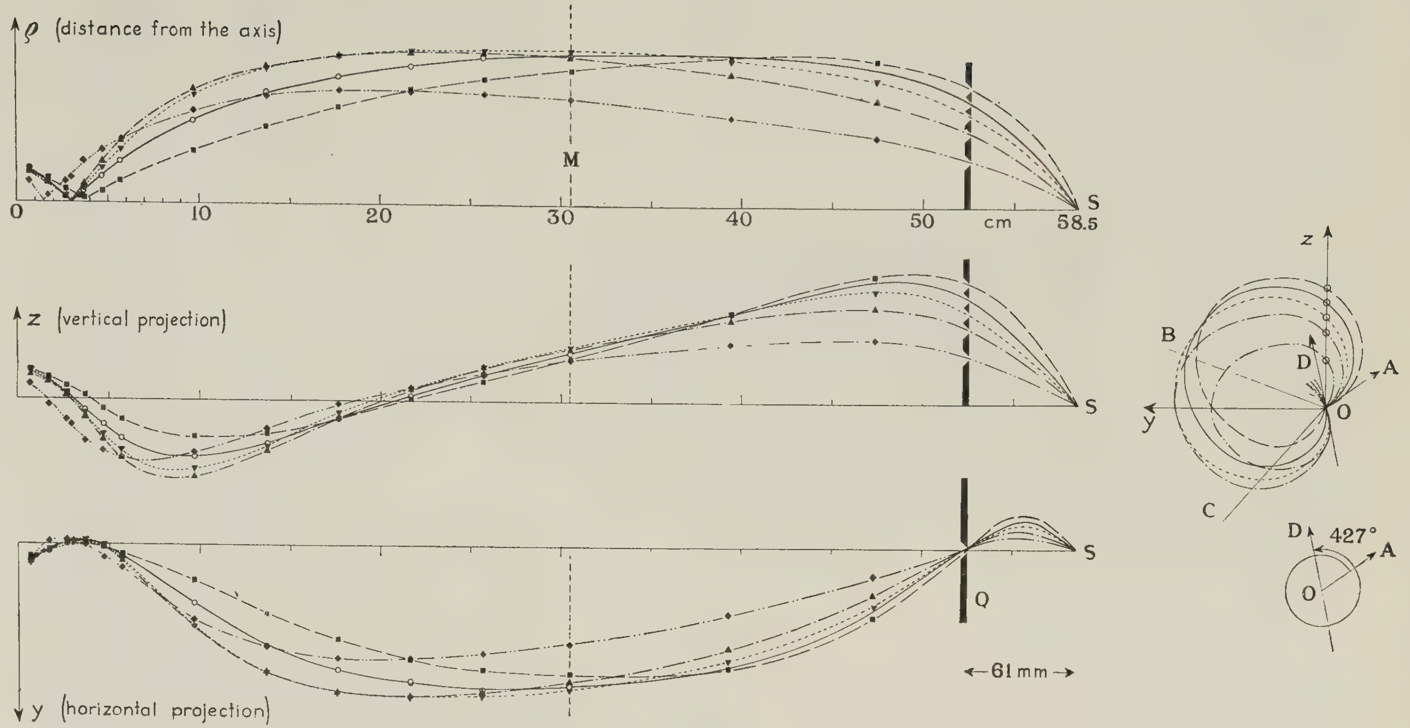

Fig. 9. Different electron paths in the high gradient field examined by the photographic method.

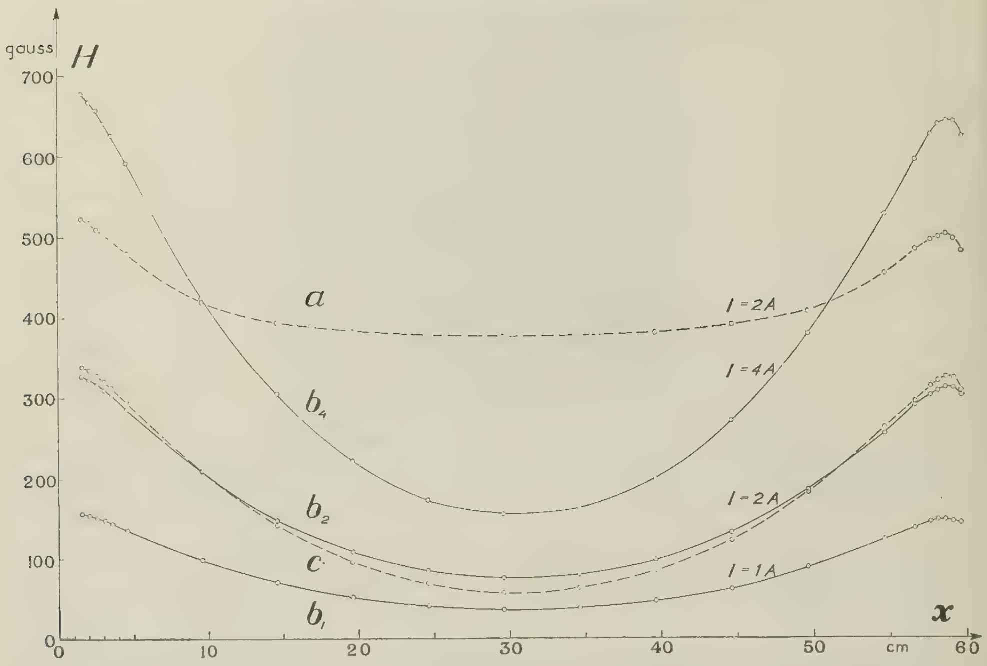

Fig. 10. Magnetic field along the lens axis, when a) the current was the same through all coils; $b_{1,2,4}$) $I_{2,3,4}/I$ was equal to 1 : 15 and the total current $I = 1, 2, 4$ amp; c) $I_{2,3,4}/I = 0$ and $I = 2$ amp.

## 5. Measurement of the magnetic field

It is sufficient to measure the field strength along the axis in order to know its value throughout the space.[1] The measurement was performed in the usual manner with a fluxmeter and a search-coil, which could be moved along the axis of the spectrometer. Fig. 10 shows the field strength along the axis when a) the current (2 amp.) was the same through all coils; $b_{1,2,4}$) $I_{2,3,4}/I$ was equal to $1:15$ and the total current $I = 1, 2, 4$ amp; c) $I_{2,3,4}/I = 0$ and $I = 2$ amp.

One important conclusion can be drawn from these curves. In spite of the iron the gradient does not change with the value of the field. This was verified up to 10 amp. This is particularly important in the actual kind of focusing, since the field gradient as well as the corresponding central shutter in practice has to be chosen once and for all. If the gradient should not be constant when focusing different electron energies the shutter $R_2$ had to be varied continuously as the gradient changed, which would be very awkward.

The relation between current vs magnetic field was carefully investigated from 0.25 amp to 10 amp. Over this large region the departure from linearity was less than ± 1% when the lens was demagnetized. 0.25 amp would focus electrons of 3 keV. The reasons for not using iron in this type of apparatus are therefore not very important.

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[1] Compare for instance K. SIEGBAHN, Phil. Mag., loc. cit.

## 6. The focusing principle

According to Fig. 9 one can draw a few general conclusions regarding the new focusing principle. First, contrary to the straight lens case we are not screening off the most valuable part of the beam, *i. e.* the one, which would correspond to axial rays. These rays are actually contained in the curved beam and constitute the outer edge of the intermediate image at the central baffle $R_2$. A very close analogy to these rays is found in the semicircular focusing case, where they form the well known sharp edge, situated at the high energy side of a given line. Actually if all shutters are removed in the lens and a photographic plate is placed in a plane along the axis in the neighbourhood of the shutter $R_2$ in Fig. 1 and subjected to the exposure of all electrons, which can emerge from the sample, a result is obtained, which is shown in Fig. 11. A surprisingly sharp edge towards the wall of the spectrometer with a gradually diminishing intensity inwards is formed by the $F$-line, in close analogy to the semicircular case. A straight lens would of course have given a uniform blackening over the whole plate. The role of the sample shutter $R_1$ is then to remove non "paraxial" rays from the beam, which otherwise would contribute to the intermediate picture, making this broader and the resolving power smaller. This shutter therefore corresponds to the $\Delta\,(H\varrho)$ defining central shutter in the semicircular case and the shutter $R_2$ to the G. M. counter defining slit in the same case. By means of the second stage in the focusing action all the electrons selected in this way, are focused to a point, where a conveniently small sized detector can be placed. The enormous gain in intensity compared to the otherwise in many respects related semicircular case, is of course given by the space focusing action instead of the one dimensional.

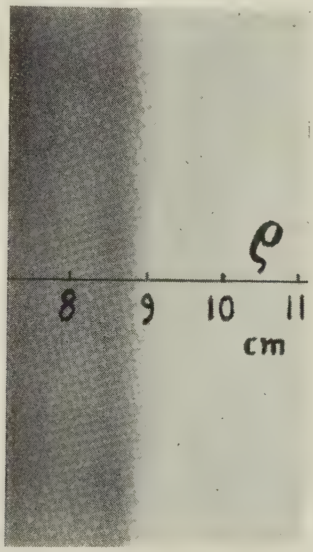

Fig. 11. The intermediate image of the $F$-line taken with a photographic plate placed parallel to the axis at $R_2$ when no shutters were in the spectrometer.

Quite recently RICHARDSON[1] has published a theoretical investigation, which deals with the case when electrons are focused in the field obtained between two pole surfaces of hyperbolic form. This paper seems to be of interest in the discussion of the actual focusing principle. If electrons are allowed to leave the source at an angle of nearly 90° relative to the axis a type of focusing takes place, which in many points is very similar to the one we have found. Thus the electron paths cross each other near the midplane between the pole surfaces, finally forming an image at the axis. Since there may be some practical difficulties connected with the choice of the field in that case (*i. e.* the G. M. counter has to collect electrons entering the counter almost perpendicular to the cylinder wall etc.) it is interesting to note that our experiments show that a large variety of inhomogeneous fields have the same essential property, namely that of forming an intermediate picture and then a final point picture. The field form can thus be adjusted to give such a focusing that the electron beam will be easy to handle, both as regard to detector and choice of sample geometry, shutters etc.

## 7. Adjustment of the β-spectrometer

It is clear from the considerations above that great care is to be taken for obtaining the optimum conditions for the β-spectrometer. The central shutter ($R_2$ in Fig. 1) can be chosen arbitrarily within certain limits. The choice of the width of the ringshaped shutter $R_2$ depends on the resolving power pursued. We have (see Fig. 12), for instance, obtained a resolving power of 1.7% when the width of the shutter was 2 mm; the diameter of the sample was then also 2 mm (it is still possible that we have not reached the inherent optimum resolving power with these parameters). When the shutter width was 8 mm and the diameter of the source 5 mm the resolving power was 4%. The transmission of the spectrometer was then almost 8% of the total radiation.

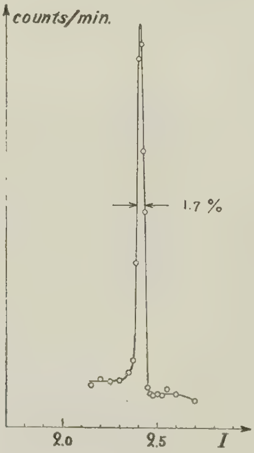

Fig. 12. The $F$-line of ThB taken with the high gradient field.

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[1] H. O. W. RICHARDSON, Phil. Mag. *XI*, 233, 1949.

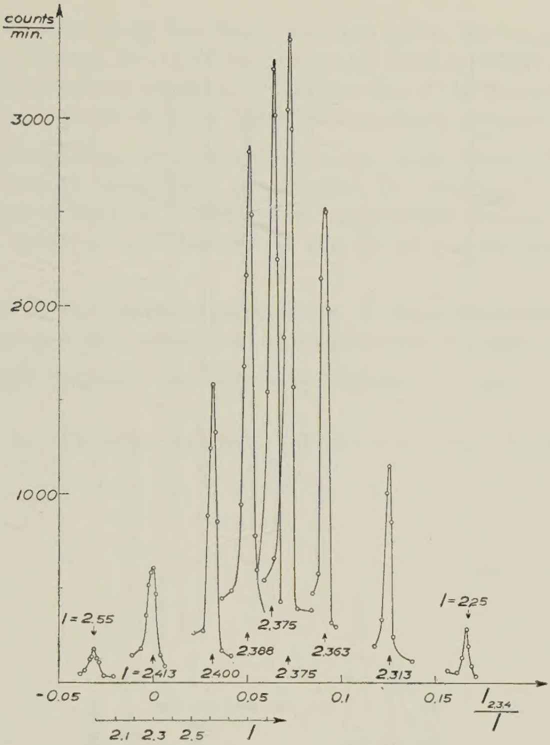

Fig. 13. Adjustment of the field gradient for a given central shutter $R_2$. The $F$-line is examined at different values of the parameter $I_{2,3,4}/I$.

A given central shutter determines the magnetic field gradient. This gradient is realized for a certain ratio of the current $I_{2,3,4}$ across the central coils to the total current $I$. The ratio is found experimentally. Fig. 13 shows the result of such an investigation. The $F$-line from ThB is taken with the G. M. counter for different ratios $I_{2,3,4}/I$. Optimum conditions are obtained for the ratio 1 : 15, and it can be seen that this ratio is sharply defined.

In a similar way the correct position of the sample is obtained. Fig. 14 shows the $F$-line of ThB for different axial positions of the sample. These positions differed only by 1 mm for each line. It is clear that the place of the sample is of great influence on the line height, and that the best position easily can be obtained from Fig. 14. If the sample is moved for instance three mm towards the pole shoe, the counting rate at the top of the line will drop down to less than 5% of its maximum value. The marked dependence on the counting rate of the positron of the sample is particularly interesting. Due to the symmetric properties of the focusing system it is evident that almost no electron, independent of energy can reach the counter slit, which emanates from other places than the properly adjusted source itself. Thus scattered radiation (for instance from points near the source), can contribute in a relatively small amount to the counting effect.

We have also looked for a possible eccentricity of the intermediate image with regard to the geometric axis of the spectrometer. No such effect was observed.

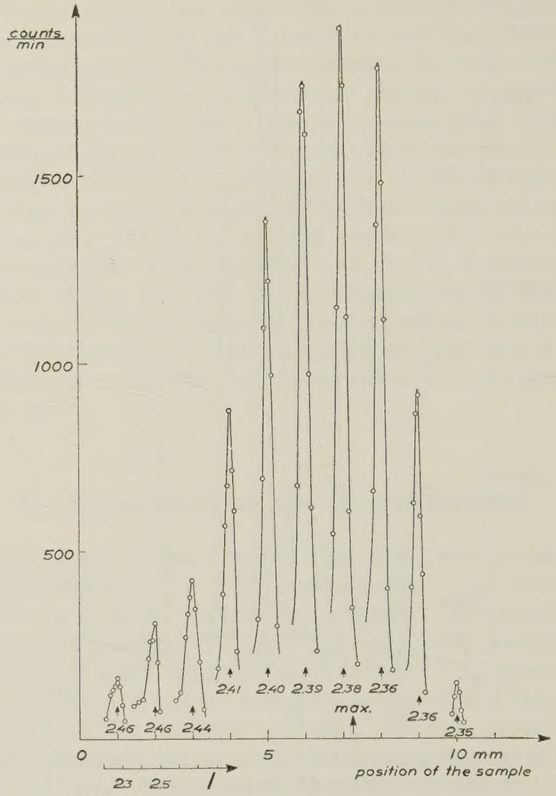

Fig. 14. Adjustment of the position of the sample.

The diameters and the position of the shutter $R_1$ must also be determined. $R_1$ is movable, and for instance the outer diameter of this shutter may thus be suitably chosen. The width is varied, and the best position for each shutter determined. One thus has to determine the maximum width of $R_1$ that will form an image of approximately the width given by the width of the shutter $R_2$. When this condition is obtained, no appreciable gain in intensity at the top of the line will occur if the shutter $R_1$ is made still wider but only a broadening of the line.

## SUMMARY

1. Some important types of electron focusing devices are discussed, especially what concerns spherical aberration.
2. A lens spectrometer is described, which has been built with the special purpose of investigating the focusing properties as a function of the magnetic field gradient.
3. Two methods have been used in the study of the focusing properties. The first is a more conventional one, using ordinary G. M. counting technique. The other is a photographic electron path tracing method using the $F$-line of ThB as a monokinetic electron source.

4. A new type of lens focusing has been observed when the magnetic gradient is made sufficiently strong, giving an exceptionally high intensity at good resolving power. Thus, at a resolving power of 4% about 8% of the total radiation is transmitted. Resolving powers of 1.7% have hitherto been attained.
5. The focusing principle has been investigated in some detail. The paths of different electron beams have been constructed by means of the photographic method. It is found that an intermediate ringformed "image" is first formed. A second, point image is then focused at the slit of a conventional, small G. M. counter.
6. The adjustments of the different parameters of the spectrometer are discussed. The field gradient and the position of the sample must be especially well adjusted.
7. The magnetic field gradient has been investigated.

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